Cloud properties at Southern Ocean derived from Ship track, aircraft and CERES-MODIS measurements and Retrievals

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Motivation

- **Southern Ocean (SO) is one of the cloudiest and stormiest regions on the Earth**

- **The majority of the aerosols are naturally produced via oceanic sources given the remote environment.**

- **The unique nature of the SO region features mixed-phase and low-level supercooled liquid clouds, which is significantly different from other regions, however we know little about how clouds form and their properties**

- **Large biases in cloud amount and microphysics over the SO in CMIP5 result in ~30 W m^{-2} SW radiation deficit at the TOA**

Objectives

Objective 1:

- **What are characteristics of SO clouds, such as CF, phase, and microphysical properties, based on the ship track and aircraft measurements?**

Objective 2:

- **Can we use these results to help CERES-MODIS (CM) to distinguish its low-level supercooled liquid and mixed-phase clouds and improve its retrieval algorithms?**

Data and Method

Measurements of Aerosol, Radiation and Cloud over Southern Ocean (MARCUS) during October 2017 to March 2018

- **WACR➔cloud profile, H_{top}**
- **MWR ➔ LWP/VAP**
- **Ceilometer –H_{base}**
- **Radiosonde- T_{base}/T_{top}**
- **MPL-rain base**
- **PSP/PIR-SW↓/LW ↓**
- **Navigation-latitude and longitude**
- **AOS-rain rate**

5-minutes averaged

CERES-MODIS pixel-level data for case study
20180105: 3 overpasses (2 Aqua and 1 Terra)
20180322: 2 overpasses from Aqua

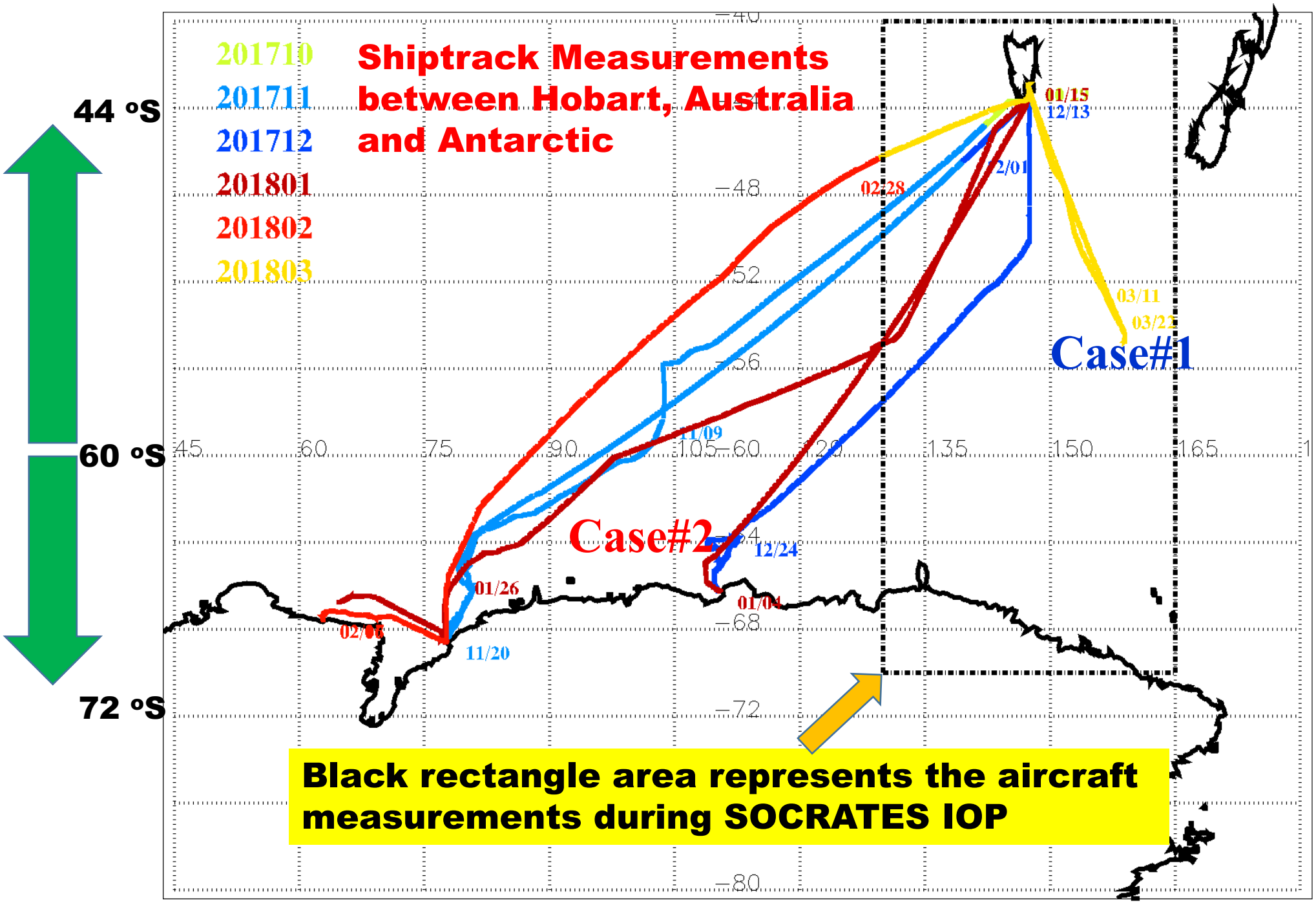
- **T_e**
- **Cloud Top/base heights**
- **LWP**
- **TAU**
- **R_e (3.75 µm)**

Selected the pixels bounded by the ship track lat-lon within a grid box of 0.5°x0.5°

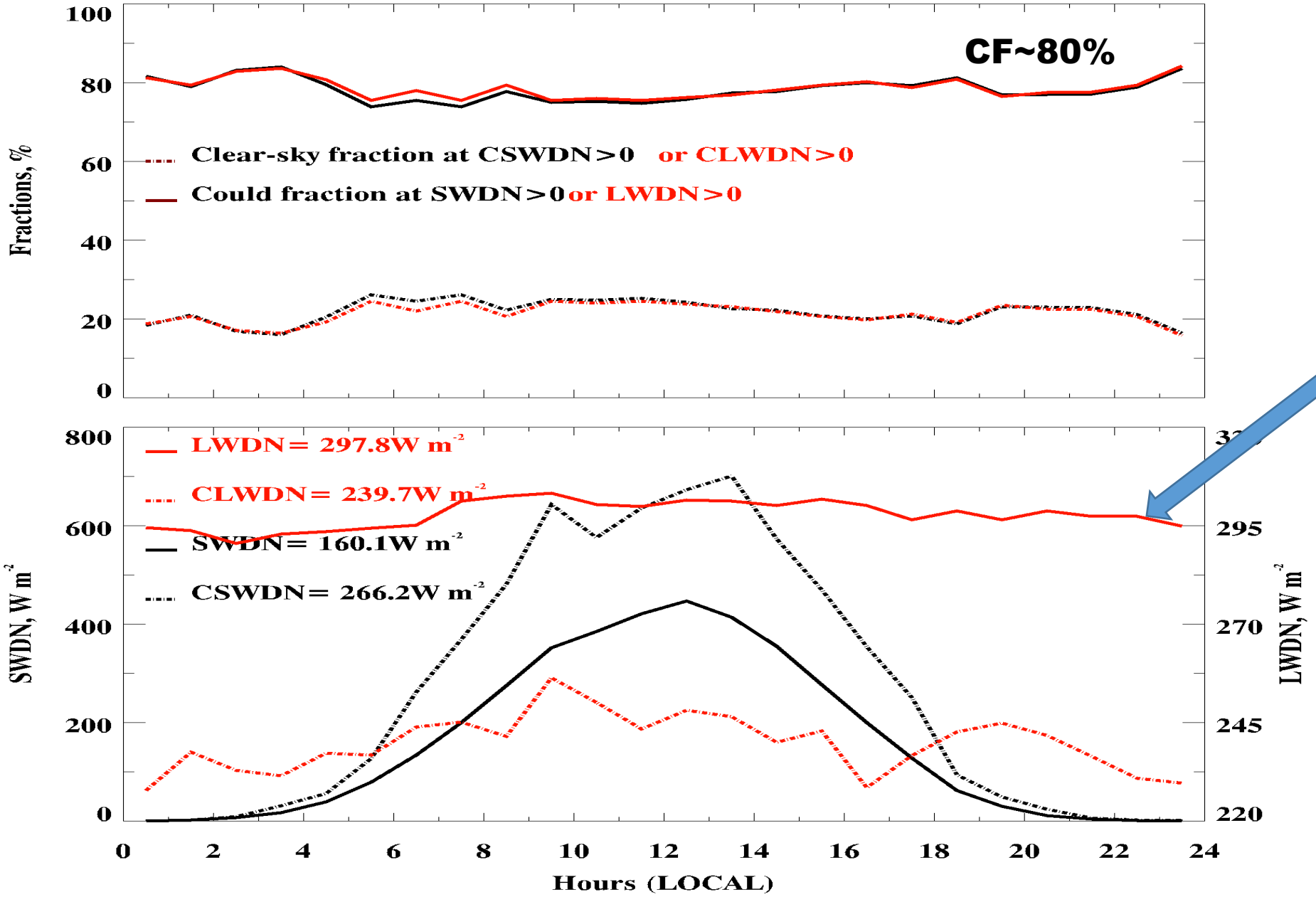
Special thanks to Mr. Mchardy, who wrote a few smart templates to process the CM data.

The Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES) during January to February 2018

- **CDP – Cloud droplet size distribution**
- **2DS – Drizzle / Ice size distribution**
- **2DS – IWC (Baker and Lawson, 2006 method)**

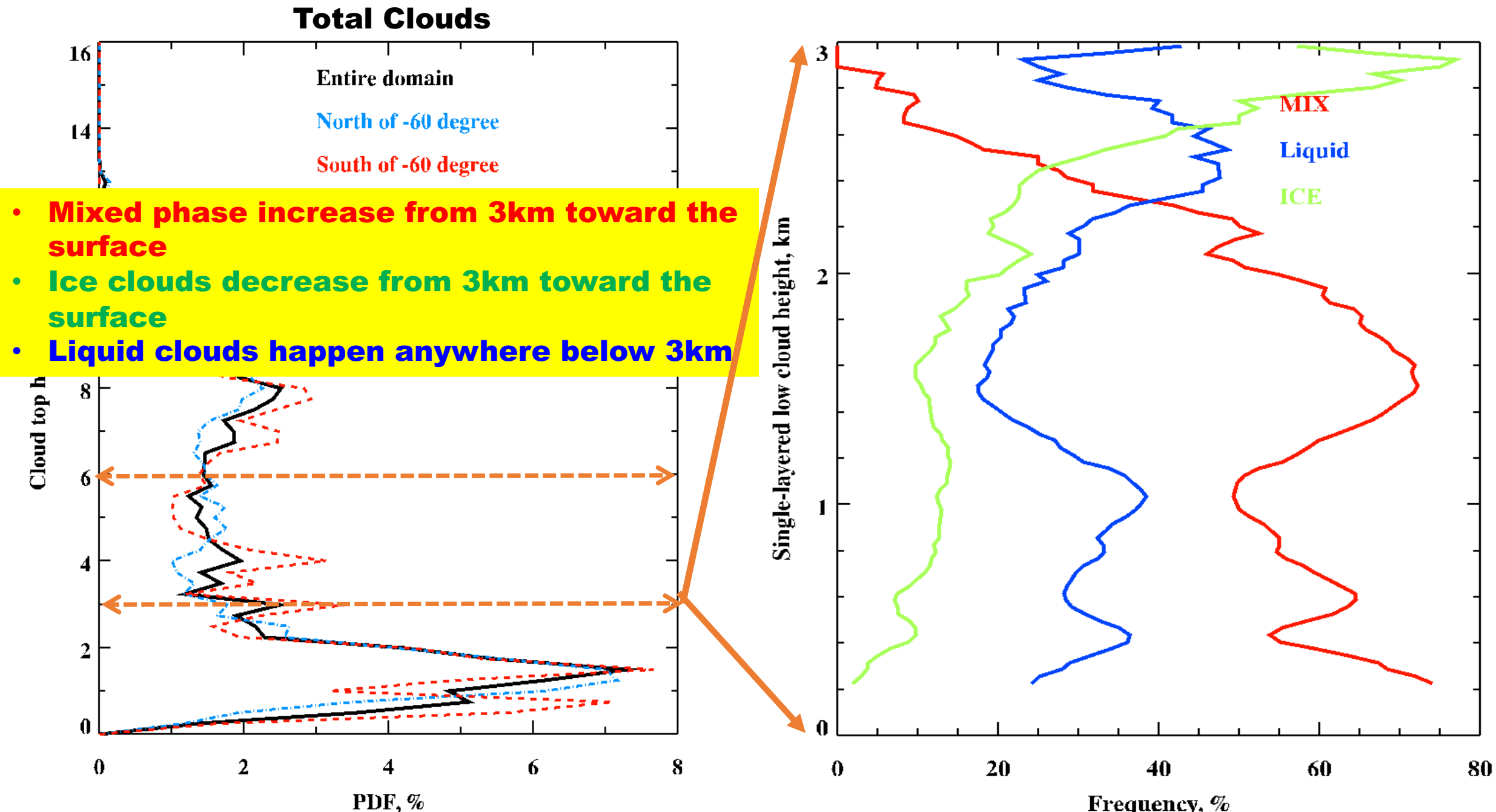

201710
201711
201712
201801
201802
201803
Shiptrack Measurements between Hobart, Australia and Antarctic
44 ºS
60 ºS
72 ºS
45
60
75
90
105
120
135
150
165
-40
-44
-48
-52
-56
-60
-64
-68
-72
-80
01/15
12/13
2/01
02/28
03/11
03/22
Case#1
11/09
Case#2
12/24
01/26
01/04
02/06
11/20
Black rectangle area represents the aircraft measurements during SOCRATES IOP

Obj. 1: Diurnal variations of SO cloud properties derived from MARCUS



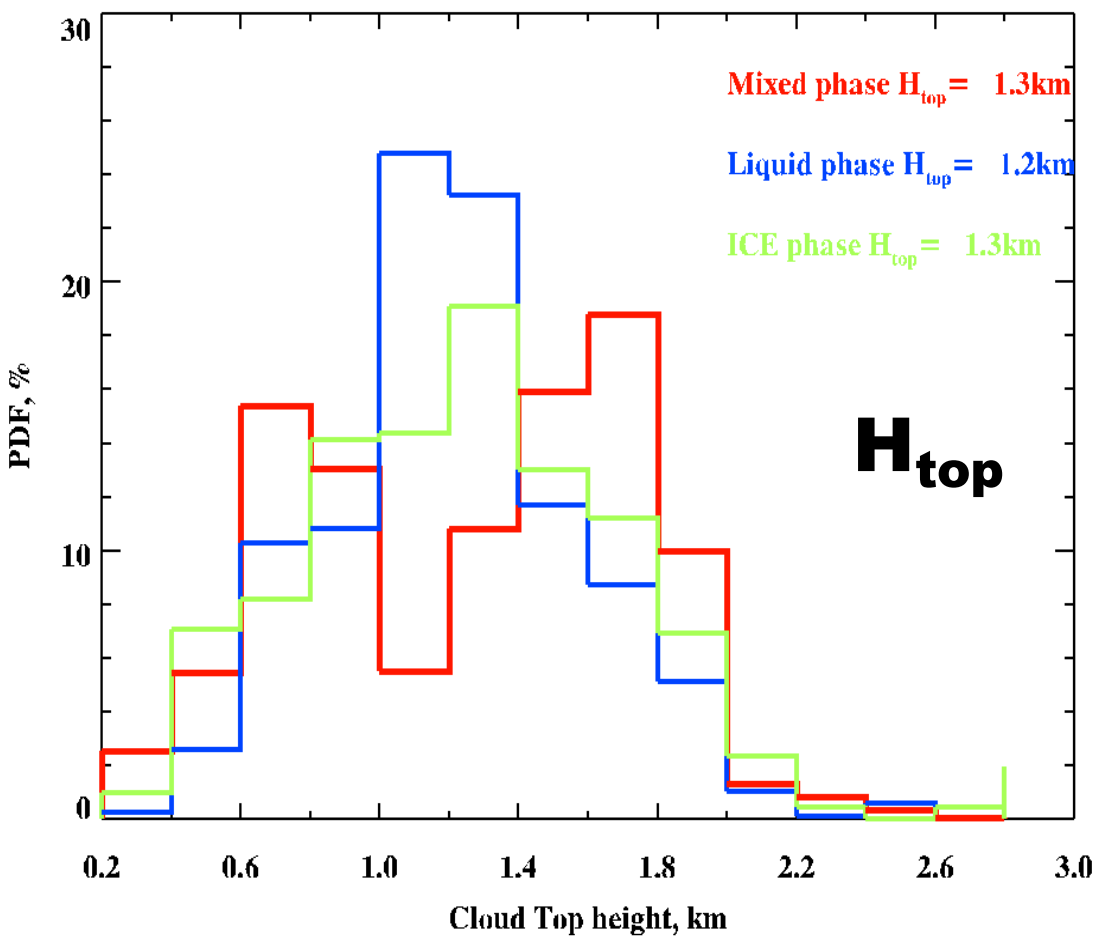
- *CF*~80% derived from ARM radar-lidar observations
- No strong diurnal variation.
- Allsky *LW* down fluxes have slightly diurnal variations, which is inversely proportional to that of the cloud fraction diurnal variation

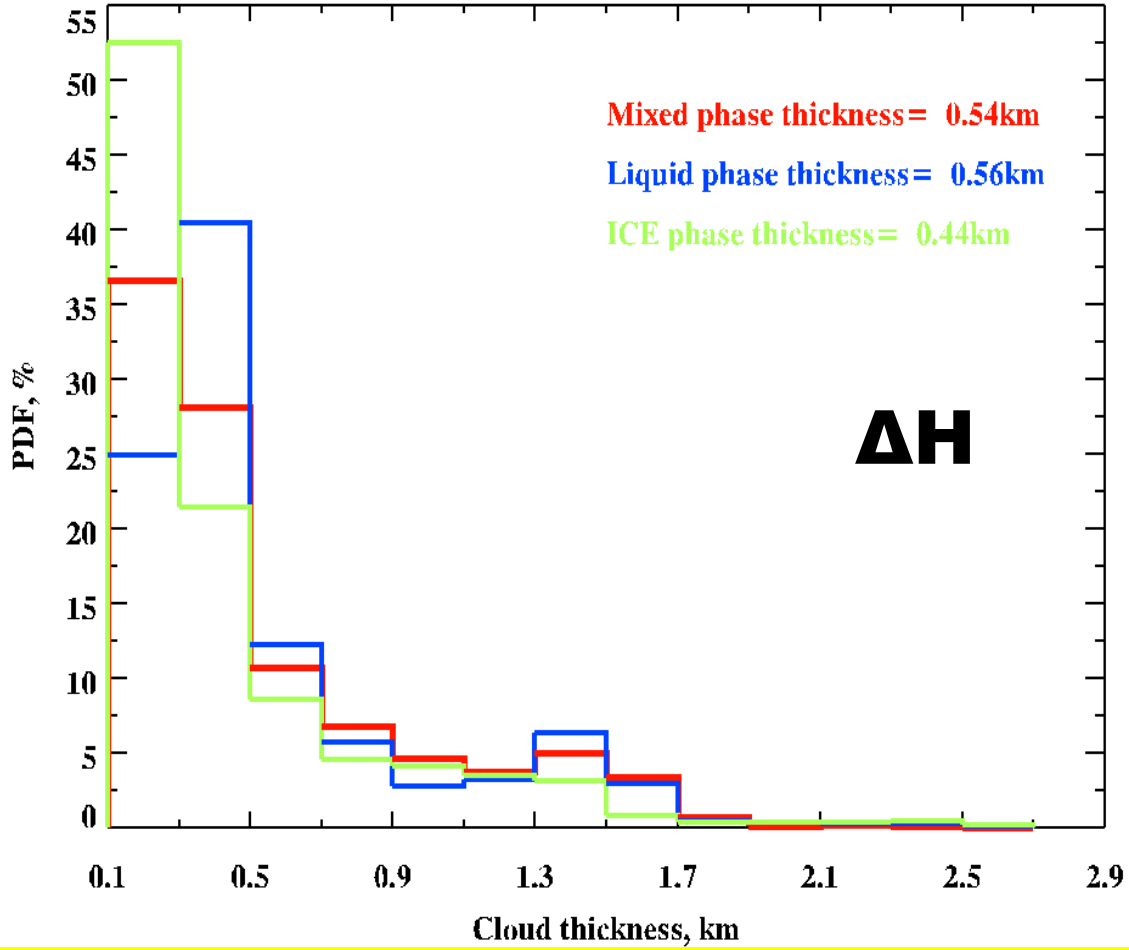
Vertical Distributions of total clouds and low clouds (H_c < 3 km)



- **Mixed phase increase from 3km toward the surface**
- **Ice clouds decrease from 3km toward the surface**
- **Liquid clouds happen anywhere below 3km**

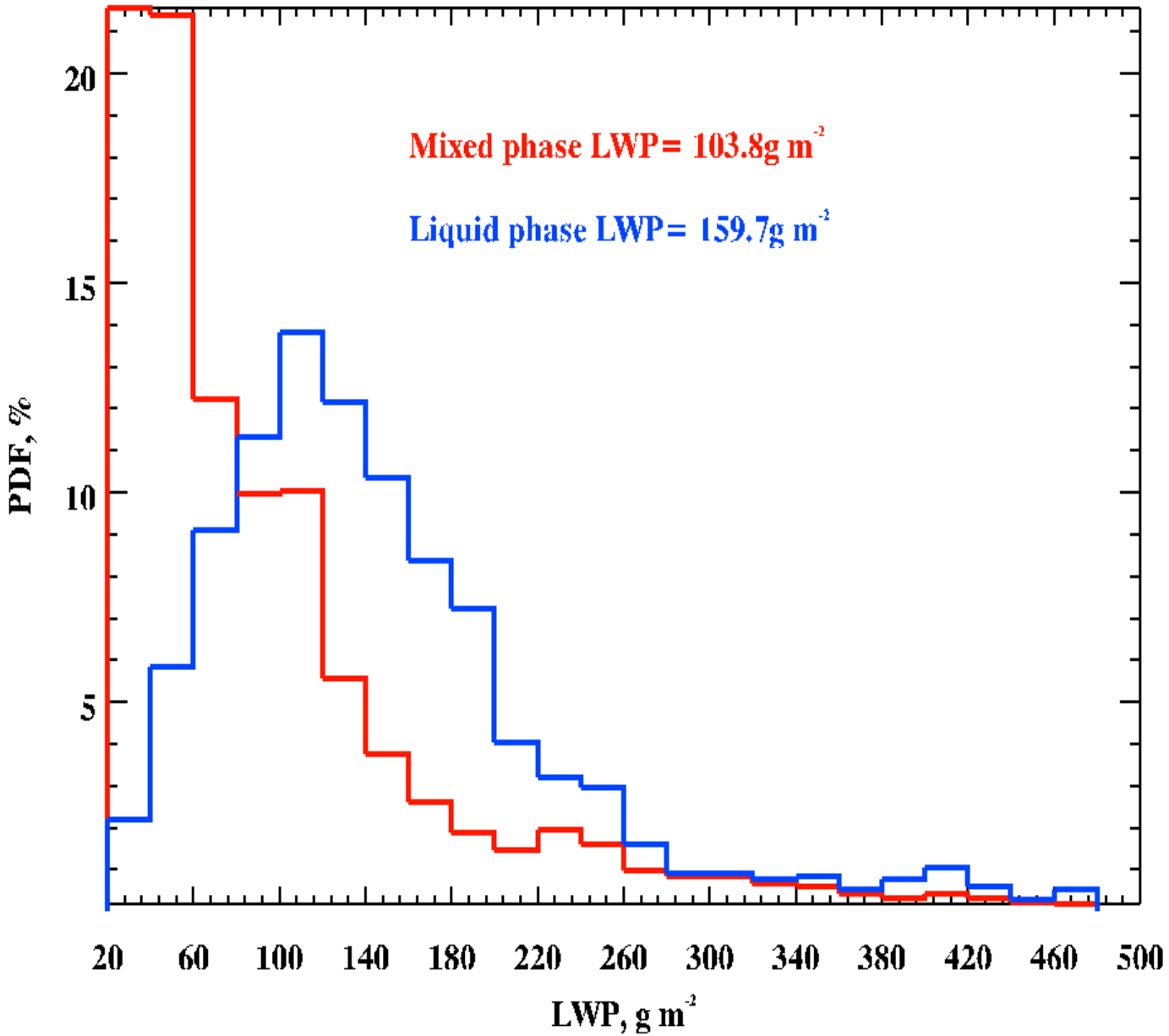
PDFs of Cloud-top height H_{top} and thickness





- **Low cloud-top heights range from 0.4 to 2 km, with almost the same mean H_{top} ~ 1.3 km for three phases.**
- **liquid and ice H_{top} have single mode, but mixed-phase H_{top} is bi-mode.**
- **Cloud thicknesses for mixed-phase and liquid are 0.54 and 0.56 km, ice is 0.44 km.**
- **Mean SO mixed-phase and liquid H_{top} and ΔH are close to Azores (1.49 and 0.56 km)**

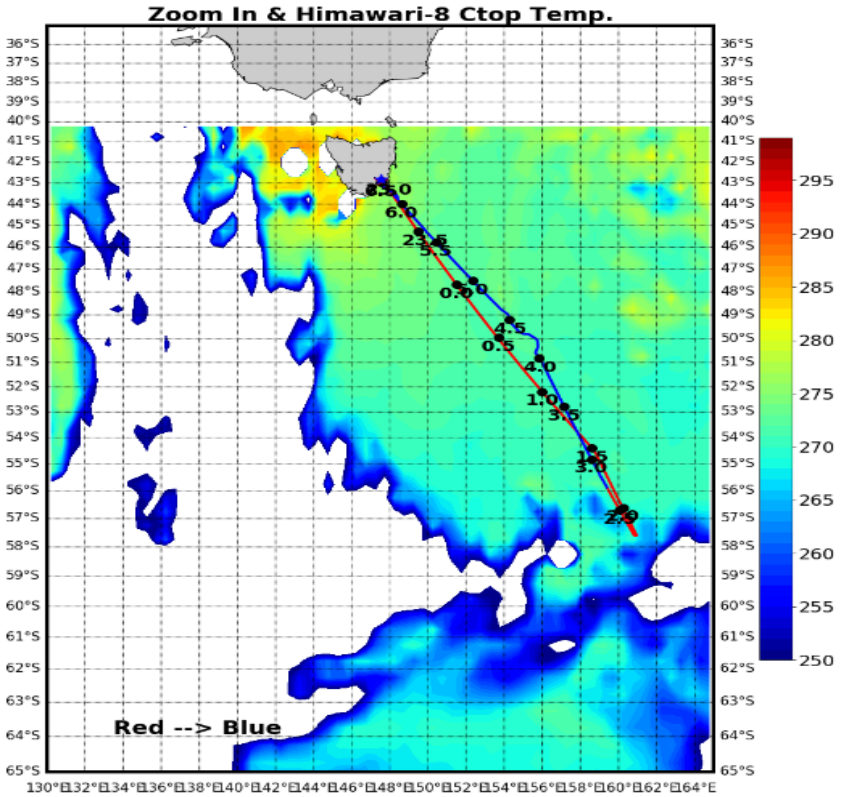
PDFs of LWPs of mixed-phase and liquid clouds

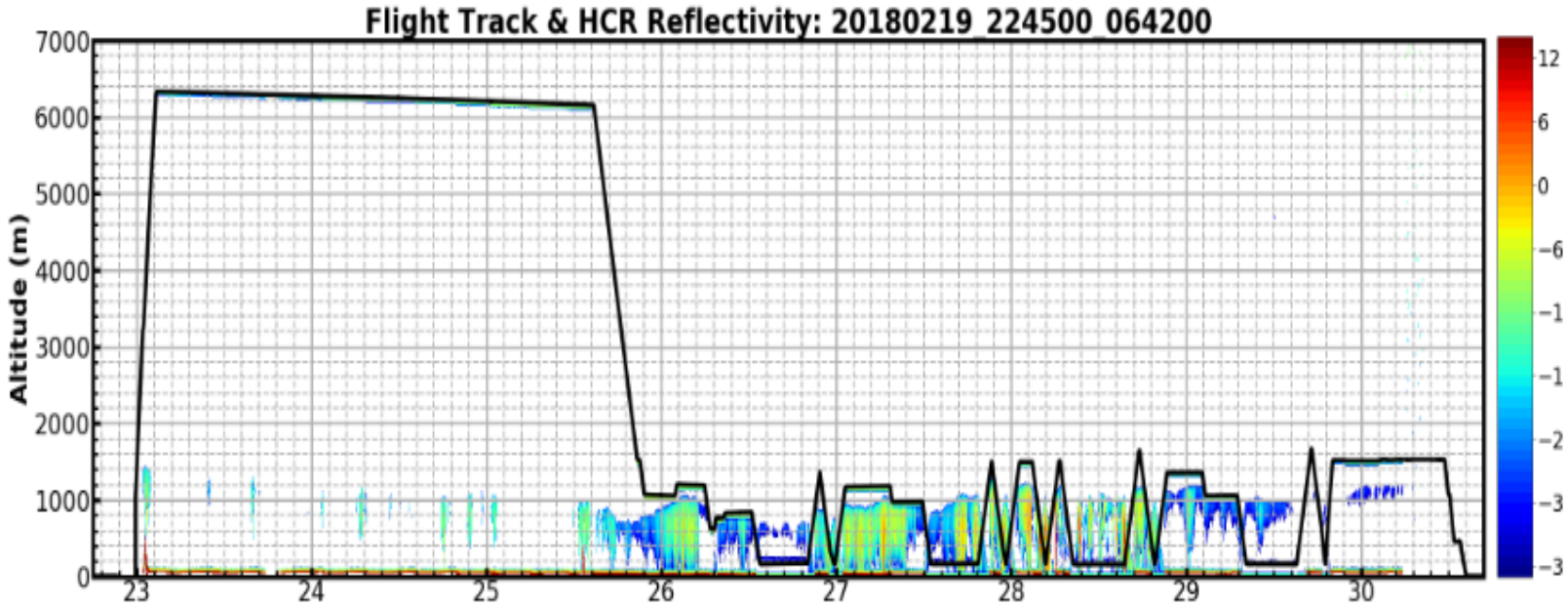


- The *LWP* modes for liquid and mixed phases are distinguishable
- The mean *LWP* of liquid phase is ~54% greater than that of mixed-phase
- Much narrower distribution of *LWP* for mixed-phase than liquid phase

The Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES)

- **Conducted during the Summer 2018 in Southern Hemisphere (Jan. 15 to Feb. 24).**
- **The NSF/NCAR GV HIAPER research aircraft flew southward from Tasmania Island of Australia to a region typically around hundreds of kilometers north of the Antarctic.**
- **There were 15 research flights (118 total hours) with aircraft in situ measurements.**





e.g. Horizontal & Vertical Flight Tracks of RF13: 20180219

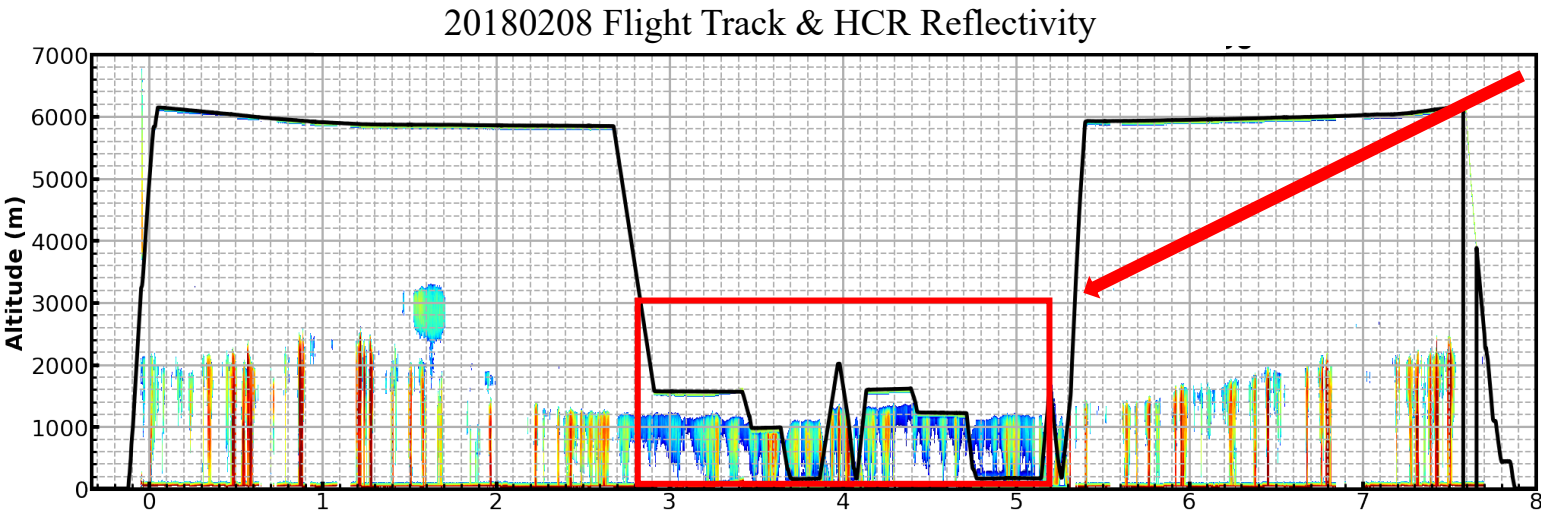
Aircraft flight strategy:

- ***Transit:***

The aircraft transited to the target region at an altitude of ~ 6000 m after take-off from the Hobart airport.
During the transit, multiple dropsondes were released to obtain the thermodynamic structures and the Radar-Lidar pair was used to detect the cloud structures.

- ***Transect:***

Aerosol and cloud properties were sampled on the way back, with legs at multiple altitudes from the boundary layer to the free troposphere.



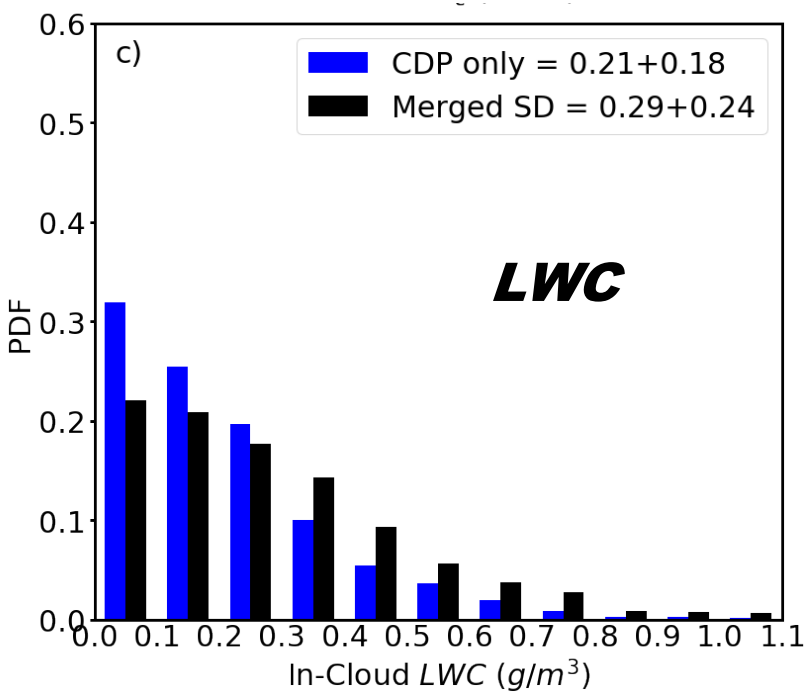
11 cases (~24 hours) of low clouds were selected for this study

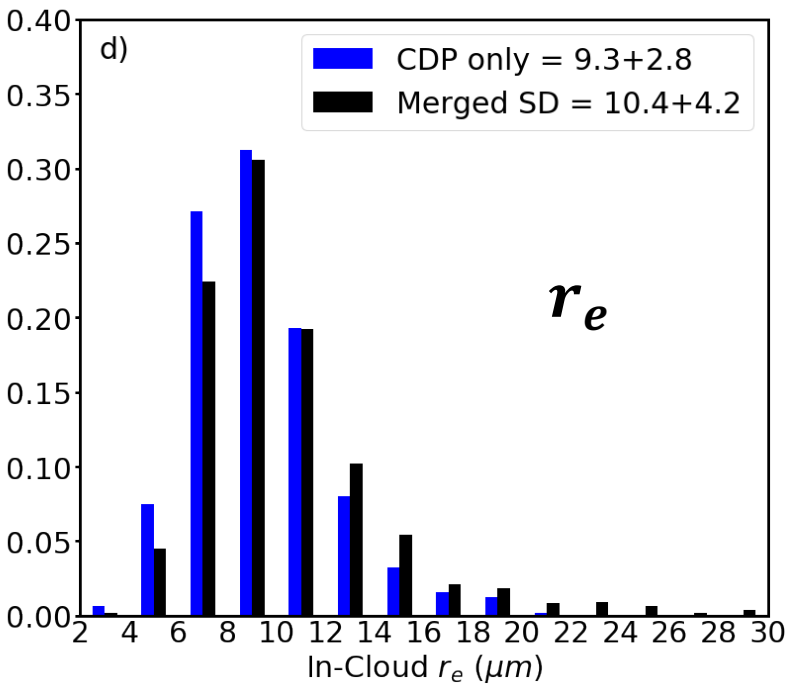
Selected low-cloud transects period		
Date	UTC* (start)	UTC* (end)
20180116	1.8	2.8
20180126	2.0	2.9
20180129	1.4	2.8
20180131	3.4	5.9
20180204	2.9	5.8
20180205	2.6	4.7
20180208	0.0	3.2
20180217	3.0	4.9
20180218	2.8	5.2
20180220	1.8	5.2
20180222	3.2	5.1

**UTC Time is the hour from 00Z on each date*

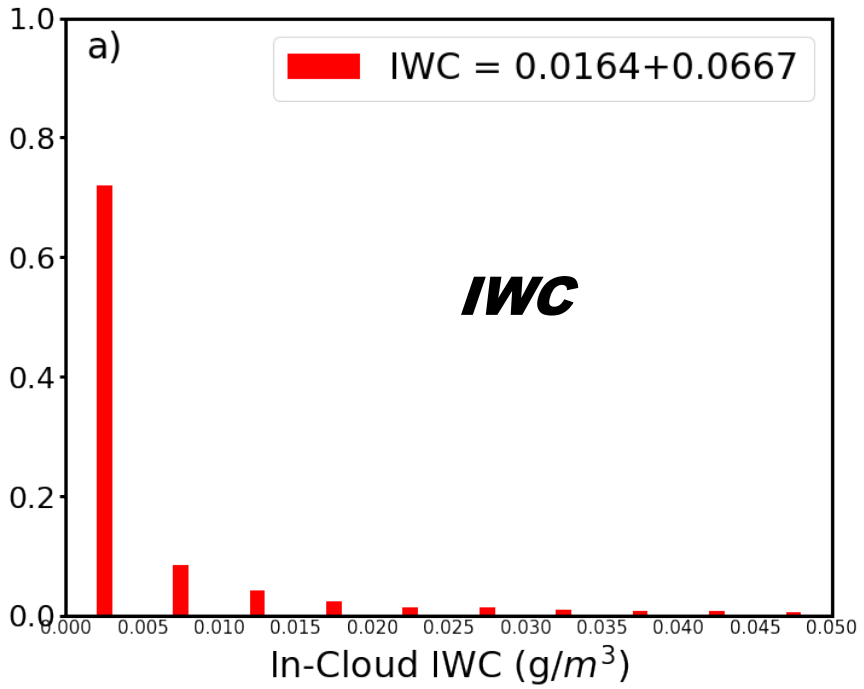
Statistics of SO low cloud properties from Aircraft (11 cases)

Liquid





Ice



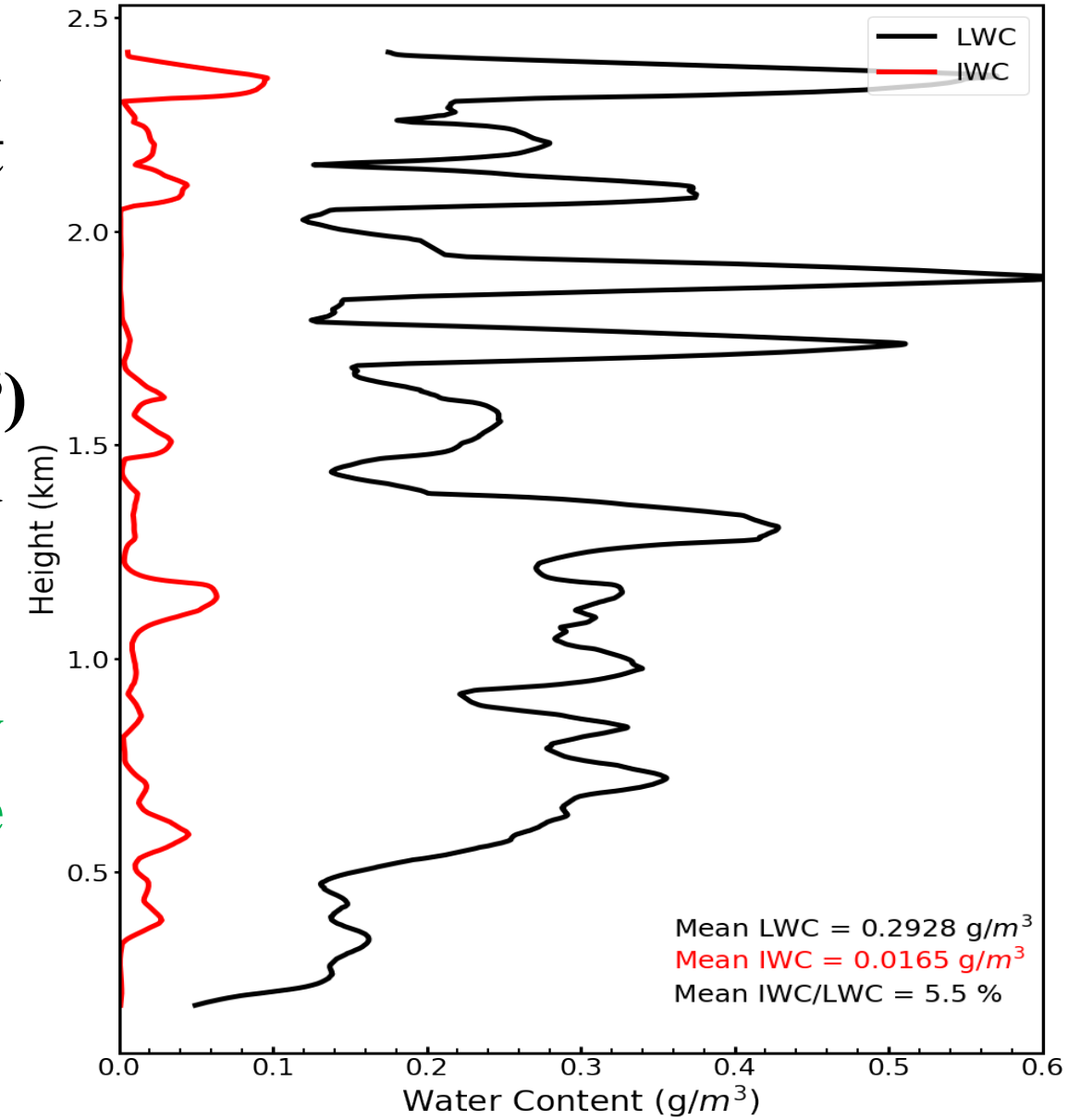
**Merged PSD: CDP ($2-45\mu m$) + 2DS ($45-5000\mu m$)*

***Sample Criteria: Total Num. Conc. > 5 g/cm^3 & Ice Num. Conc. > 0 g/cm^3*

- From CDP only, mean liquid cloud LWC and r_e are 0.21 gm^{-3} and 9.3 µm.
- From Merged, including drizzle, their mean LWC and r_e are 0.29 gm^{-3} and 10.4 µm.
- *Most IWC values* < 0.01 gm^{-3}, with a mean of 0.0164 gm^{-3} and large variation

Vertical Distributions of IWC/LWC (selected cases)

- **Vertical distribution of *LWC* & *IWC* using all the ice-present samples.**
- **The ratio of mean LWC (0.293 gm^{-3}) to IWC (0.0165 gm^{-3}) is ~18, liquid particles are dominant.**
- **Aircraft in-situ measurements show comparable the ratio of liquid/ice derived from Radar.**



Summaries of Objective 1

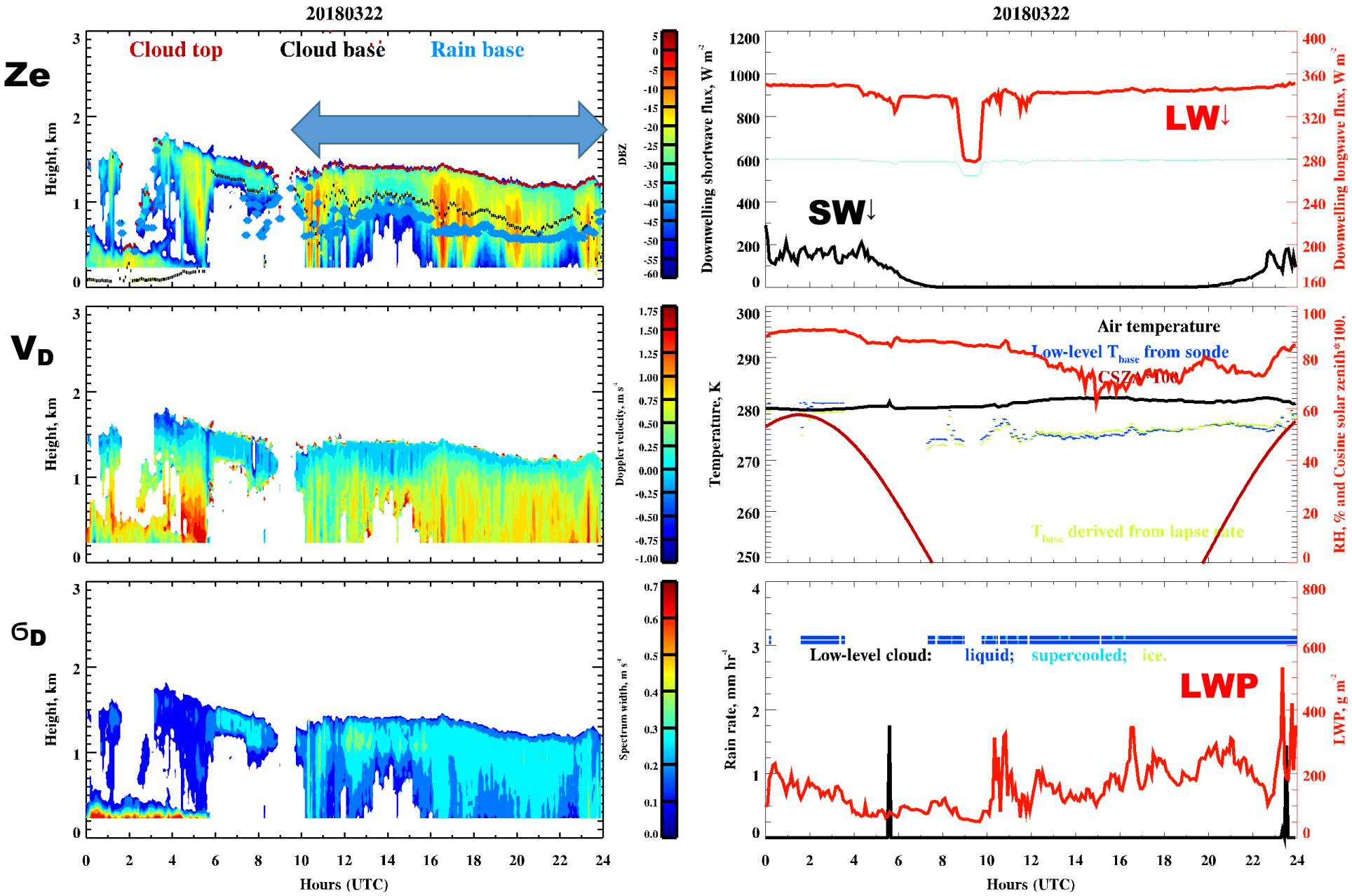
- Based on ARM radar-lidar data, the total cloud fraction is ~80%, and low-level clouds are dominant during MARCUS IOP
- Mixed phase increase from 3km toward the surface; Ice clouds decrease from 3km toward the surface; Liquid clouds happen anywhere below 3km
- Mean SO mixed-phase and liquid H_{top} (1.2 - 1.3 km) and ΔH (0.54 – 0.56 km) are close to MBL clouds at Azores (1.49 km and 0.56 km)
- The mean *LWPs* for liquid and mixed phases are 160 and 104 gm^{-2}, respectively, the liquid LWP is higher than MBL clouds at Azores (~125 gm^{-2})
- Mean LWC is 0.29 gm^{-3}, which is also higher than that at Azores, and r_e is 10.4 μm, which is smaller than Azores retrievals and aircraft data.
- Mean IWC is 0.0165 gm^{-3}, which is only 6% of total water content.
- The SO mixed-phase clouds are different to those at ARM Arctic site:

Liquid and ice coexist vertically at Southern Ocean, Liquid on the top of ice layer at NSA

Objective 2:
Cloud properties observed by ARM and derived from CM for Cases 1 (liquid) and 2 (mixed)

- **Cloud heights derived from ship track radar and CM measurements**
- **The cloud temperature from radiosonde and CM measurements**
- **The cloud microphysical properties from our retrievals and CM Ed4 pixel data**

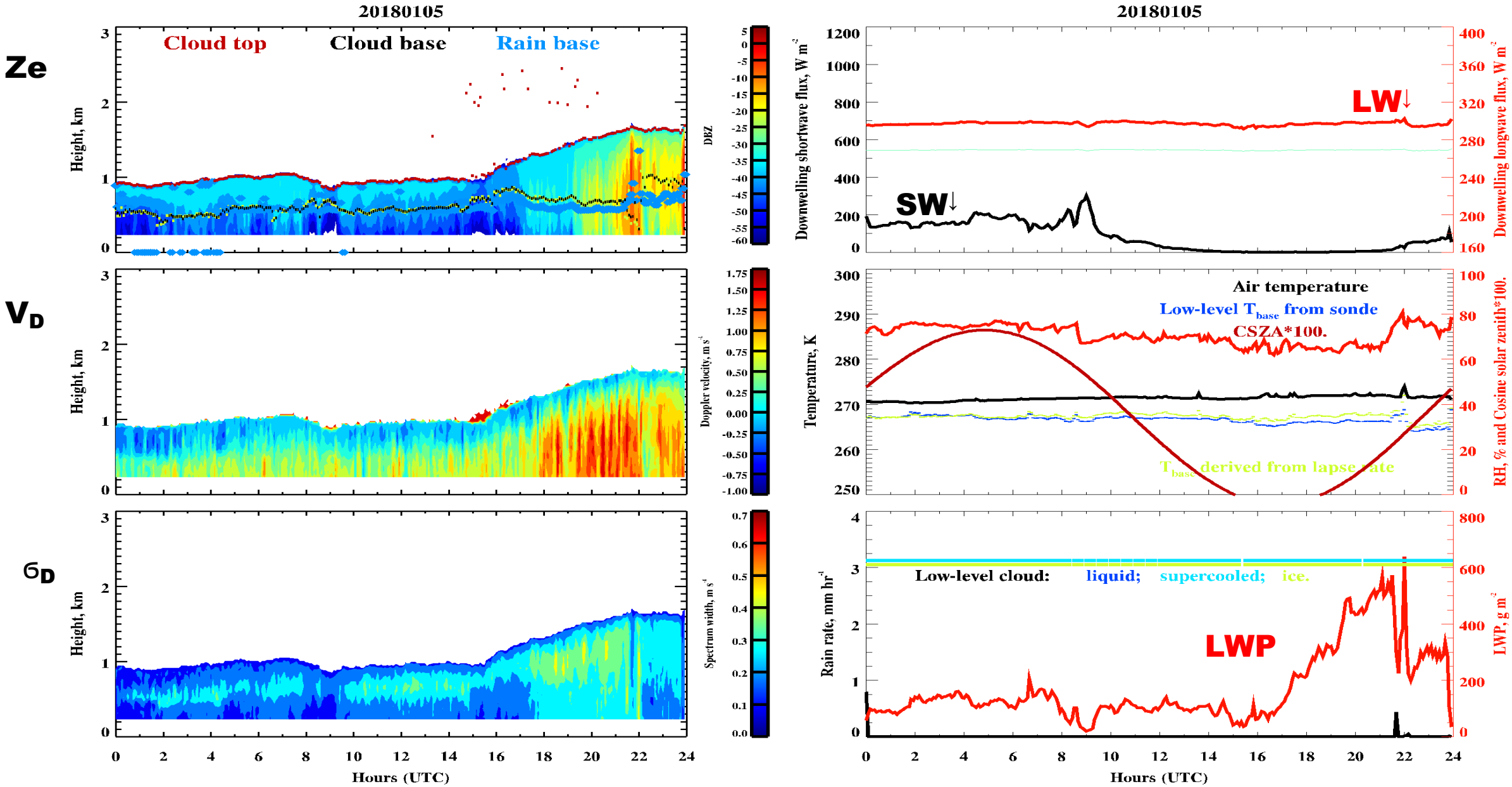
Case #1: 20180322: Liquid Clouds



Selection criteria:

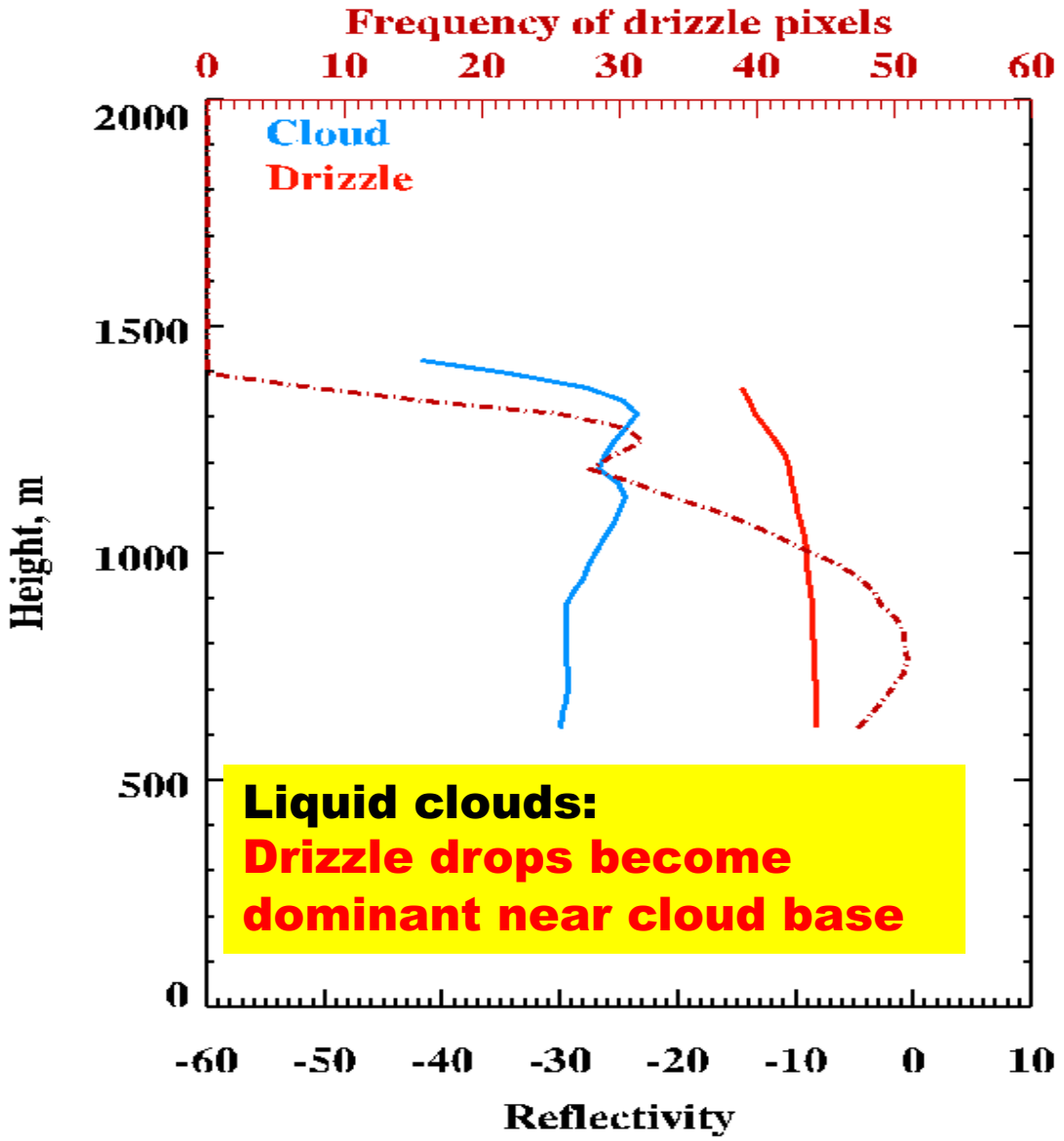
- **Continuously, single-layered, low-level clouds**
- ***T_{base}* and *T_{top}* > 0 ^{o}C**
- ***LWP* > 20 g m^{-2}**

Case #2: 20180105 Mixed-phase clouds (T<0°C, LWP>20 gm^{-2})



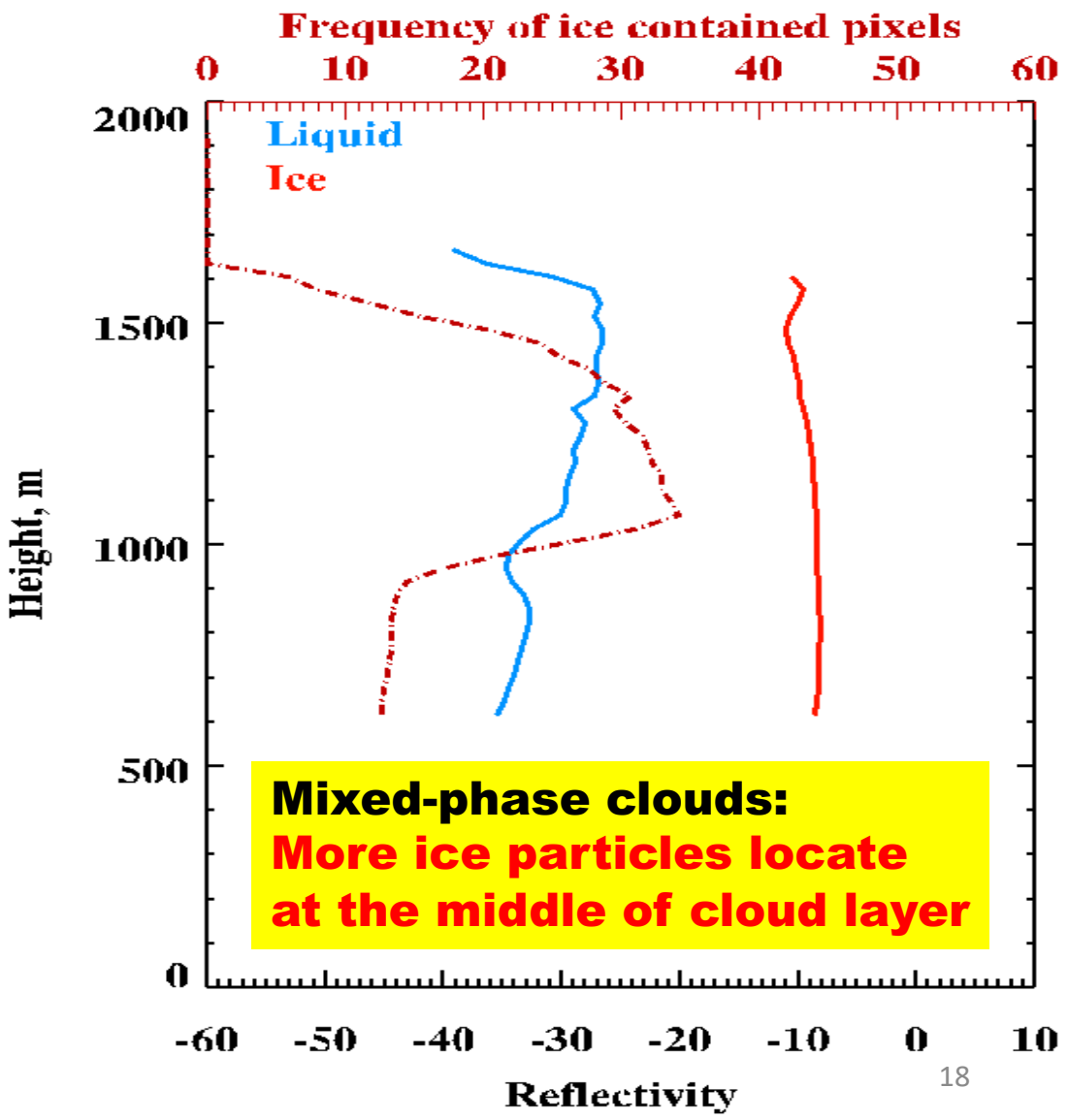
Using the method of Shupe et al. (2007) to show the profiles of liquid, drizzle and ice clouds using ARM radar-lidar measurements

Case#1: 20180322



Liquid clouds:
Drizzle drops become dominant near cloud base

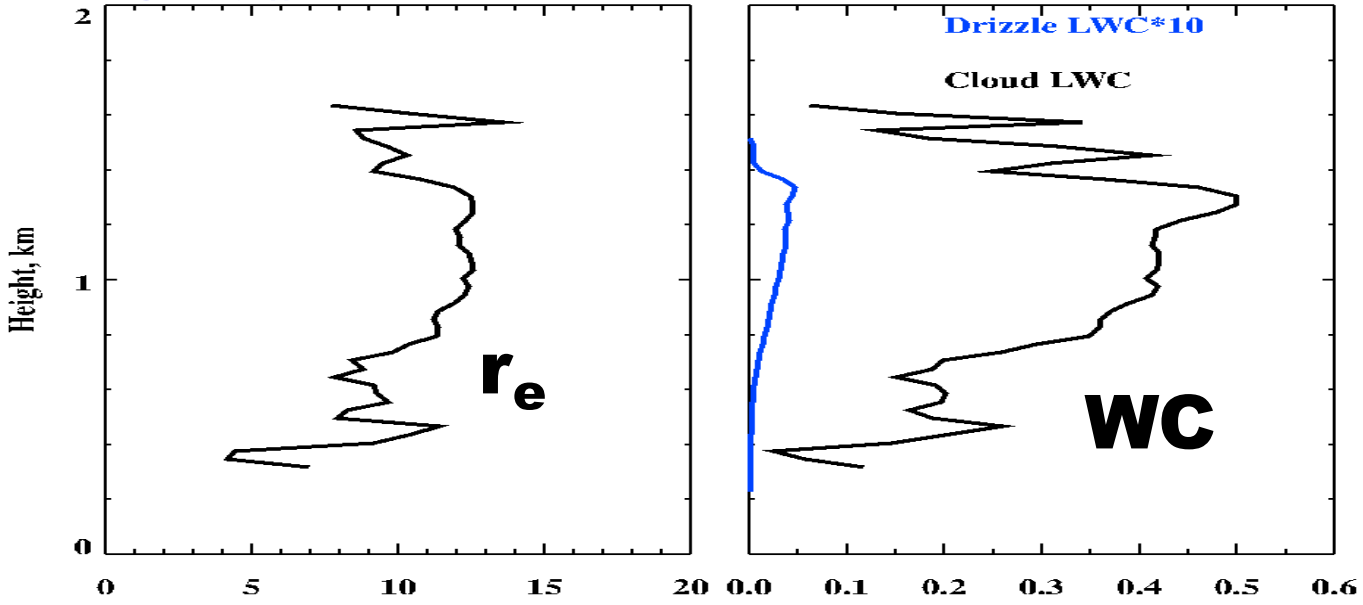
Case#2: 20180105

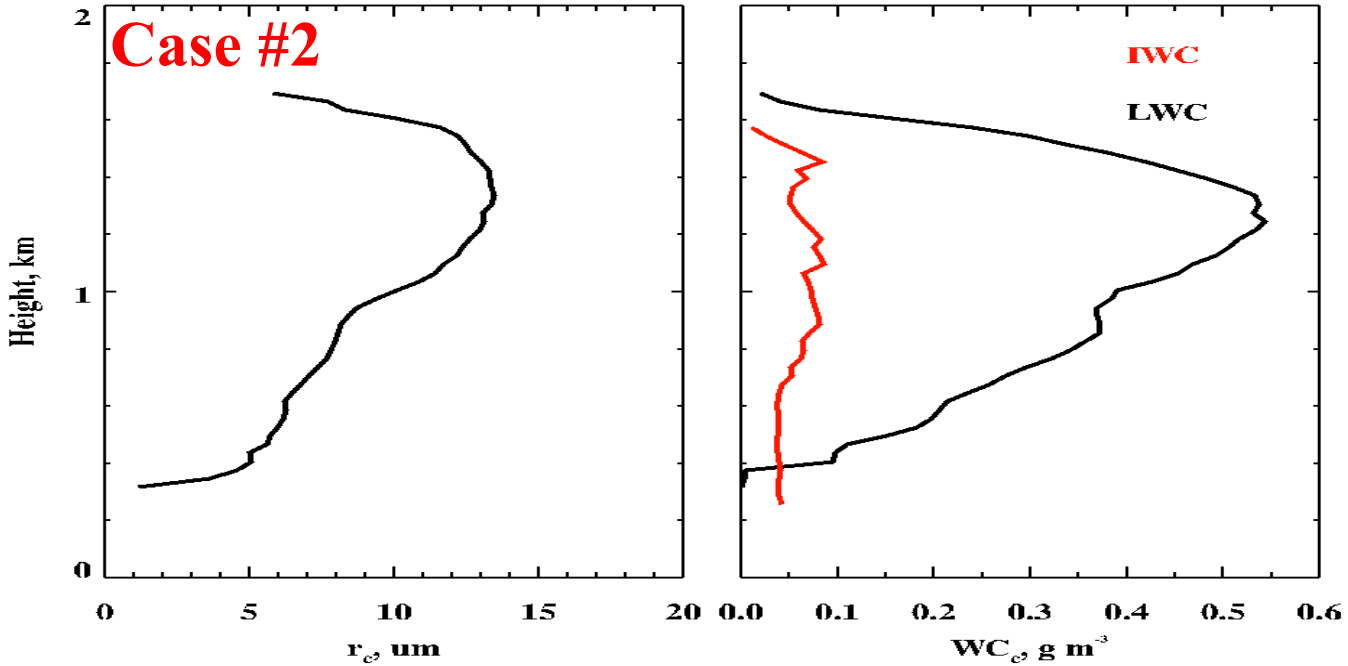


Mixed-phase clouds:
More ice particles locate at the middle of cloud layer

Retrievals of cloud properties using surface data

Case #1

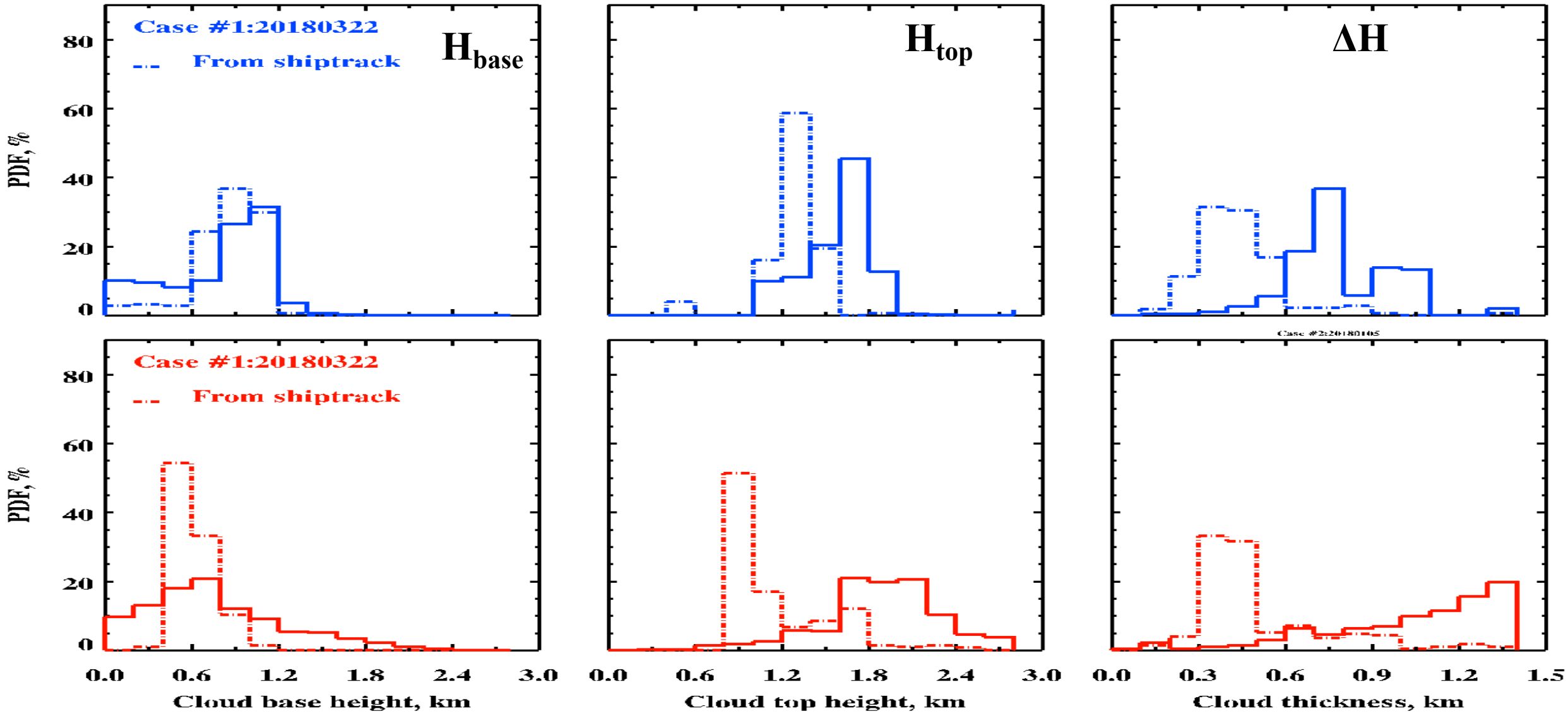




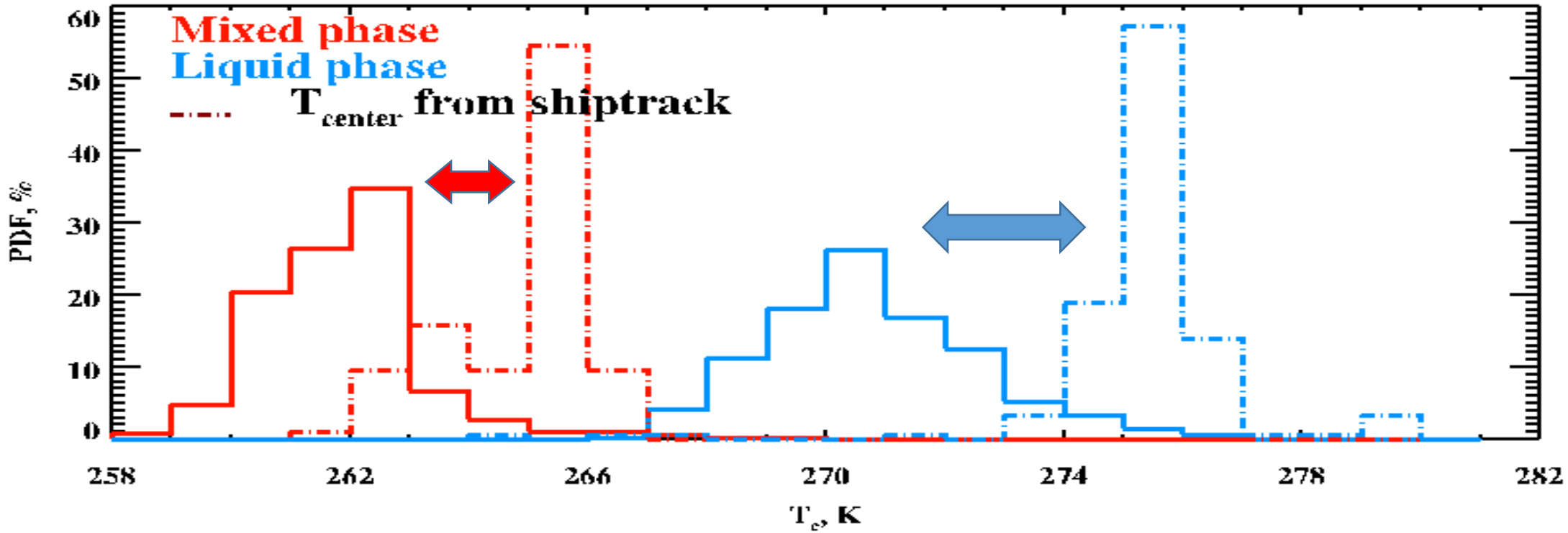
Liquid and drizzle properties retrieved from Wu et al. (2020), and ice properties retrieved from Matrosov (1999)

- **Both retrieved r_e and LWC increase with height, reach maxima at ~75% of the cloud layer.**
- **For Case 1, the cloud LWC~ 100 * drizzle LWC.**
- **For Case 2, LWC ~ 10* IWC**

Cloud height comparisons for two cases between SHIP track and CM

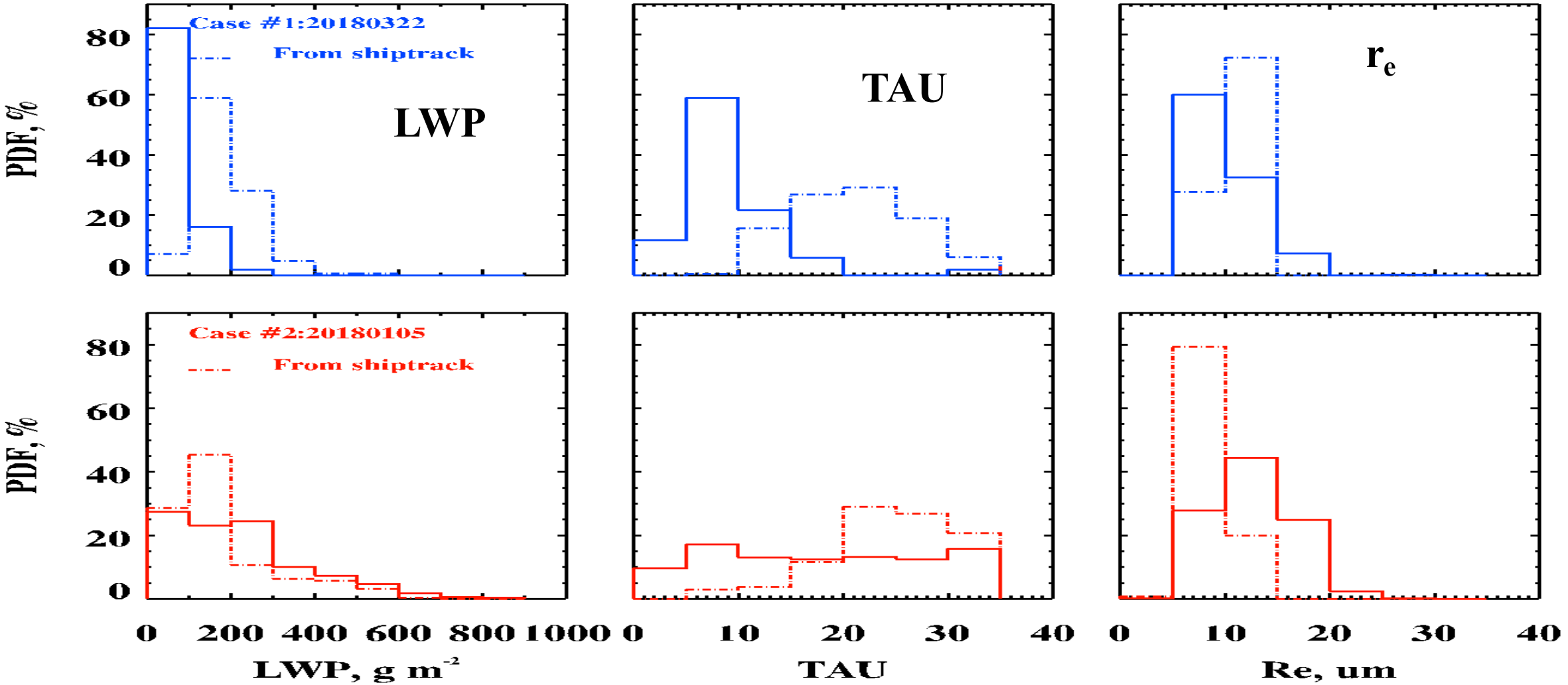


- Case I: H_{base}: almost the same; H_{top}: CM has higher mode (solid line) → ΔH CM is higher and bi-mode
- Case 2: CM derived H_{base}, H_{top}, ΔH have wider distributions with larger values than ship measurements



- **CM cloud temperature is much colder than these from ARM measurements, which is consistent to the cloud top heights are higher than ARM for both cases**
- **CM derived T_{eff} values for both cases are lower than ARM observations, that imply the cloud emitted center closer to the cloud top**

Cloud microphysics comparisons for two cases between SHIP track and CM



- CM LWPs agree well with ARM MWR retrievals for Case 2 but much less for Case 1.
- CM r_e (3.7um) retrievals are smaller than surface retrievals for Case 1, but larger for Case 2.
- CM Tau retrievals for both cases are smaller than surface retrievals, especially for Case 1.

Summaries of Objective 2

Cloud height and temp comparisons:

- Liquid phase Case 1: H_{base}: almost the same; H_{top}: CM has higher mode (solid line) → ΔH CM is higher and bi-mode
- Mixed-phase Case 2: CM derived H_{base}, H_{top}, ΔH have wider distributions with larger values than ship measurements
- CM derived T_{eff} values for both cases are lower than ARM observations, implying the cloud emitted center closer to the cloud top.

Cloud microphysics comparisons:

- CM LWPs agree well with ARM MWR retrievals for Case 2 but less for Case 1.
- $CM\ r_e$ (3.7um) retrievals are smaller than our retrievals for Case 1, but larger for case 2.
- CM Tau retrievals for both cases are smaller than surface retrievals, especially for Case 1.

Future plans

- Repeat the results from more cases
- Retrieve the mixed-phase cloud properties

- Analyze other parameters from CERES-MODIS and find any relations between these parameters to the microphysical properties of mixed-phase clouds

Thanks for your attention

Backups

SOCRATES 2DS Drizzle Statistic

Drizzle droplets & Ice particles ($D_p > 200\mu m$) were detected by 2DS ($45 - 5000\mu m$)

Drizzle droplet Num. Conc. obtained by $N_{total} - N_{ice}$ in every size bin

In SO low-cloud:

Drizzle droplets have **small Num. Conc.,** but **large droplet sizes.**

Drizzle Microphysical Properties (Drizzle-droplet-only)